CHAPTER 2. MECHANICS OF BLASTING

2-1. Explanation. The mechanics of blasting are treated in this chapter in a simplified manner to point out basic principles and conditions. References 1 and 2 were used as the sources of much of the information. Supplementary information on rock damage from blasting is found in Chapter 7. The word "explosive" as used herein is defined as a chemical compound or a mixture of compounds that reacts to liberate heat or mechanical energy by decomposing rapidly into other compounds, mostly gases.

2-2. Partitioning of Energy. Although complicated, the general mechanics of blasting are now at least partially understood. Three main stages of blasting are pressure buildup, wave transmission, and airblast.

a. Peak Pressure and Shock Wave. Explosion gases occupy a much greater volume at ordinary confining pressures than the original charge and are capable of building up transient peak pressures of 10^5 atmospheres (atm) or more in the vicinity of the charge. A resulting shock wave generated within a few milliseconds (msec) following detonation propagates away from the explosive charge. Even the strongest rocks are shattered in the immediate vicinity.

b. Elastic (Seismic) Waves. Work is performed in crushing rock surrounding the charge, and consequently the initial shock wave begins to decay in intensity after leaving the point of detonation. At a relatively short distance the compressive pulse is reduced to a level of intensity below the compressive strength of the rock. From this point on rock crushing stops, but other pressure or primary (P) and shear (S) waves continue through the rock mass. The velocity of the P-wave varies mainly according to the elastic properties of the rock. In weak rock, it will travel approximately 5,000 to 10,000 feet per second (fps) and in strong rock with little jointing, it will travel as fast as 20,000 fps. P- and S-waves perform work by moving the rock particles longitudinally and transversely. For this reason, the waves will attenuate until they eventually die out or until a free face is encountered. The distance of travel of these waves is measured in hundreds and thousands of feet in construction blasting. These waves are of considerable importance in regard to damage and vibration control (Chapter 7).

c. Air Waves. A portion of the energy that reaches the free face as a P-wave may be transferred to the air in the form of an air wave (para 7-2).

2-3. Fragmentation Near an Explosion.

a. Zones of Deformation.

(1) Fig. 2-1 shows fracturing and deformation zones around the explosion. This illustration represents a spherically symmetric picture

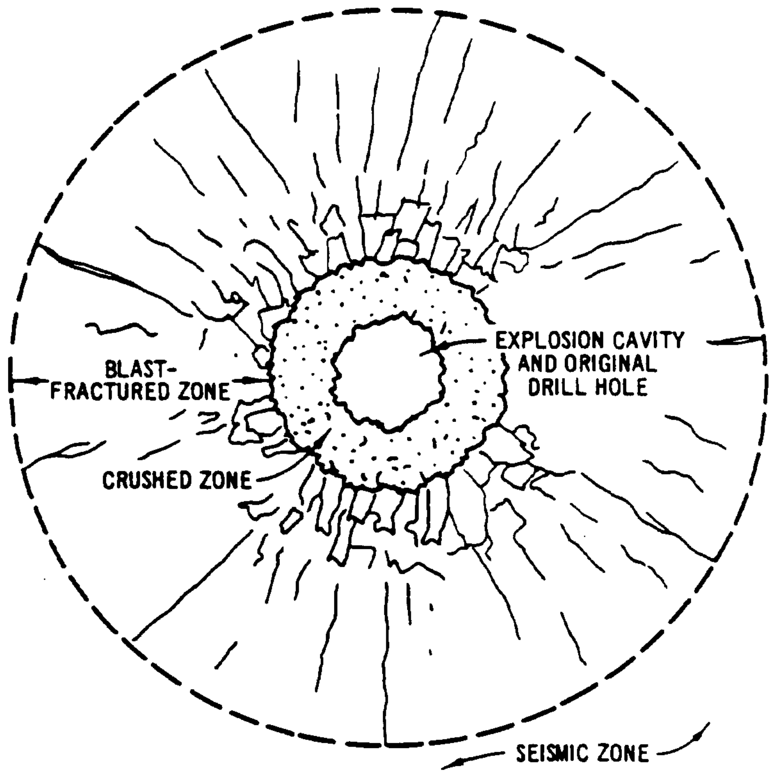


Fig. 2-1. Zones of fracturing and deformation around an explosion in rock

for a spherical charge or a section perpendicular to the axis of a cylindrical charge. The rock medium assumed for this illustration is essentially infinite in extent so that the effects of free boundaries are not included.

(2) Four major zones can develop. The first is the explosion cavity (essentially the original charge cavity) where the process is hydrodynamic. The second and third zones are the crushed and blast-fractured zones, respectively, where the shock pressure is rapidly reduced as a result of plastic flow, crushing, and cracking. The fourth zone is the seismic zone, where the stress is below the elastic limit and no fragmentation occurs, except near free boundaries as discussed below.

The crushed zone is minimized or eliminated in well-designed pre-splitting (para 5-4a).

(3) Crushing and fracturing are functions of the explosive type, charge loading, and the rock parameters. The size of the crushed zone is usually larger in rocks of lower compressive strength. Use of explosives with low detonation pressures or decoupled charges (isolated from rock by air space) in competent rock may reduce crushed zones and control the extent of the blast fracturing. The crushed zone typically extends to about twice the charge radius.[3] The radius of the blast-fractured zone is typically about six times the radius of the crushed zone,[3] or about three to four times the radius of the crushed zone adjacent to a very large point charge.[4] The spacing between fractures increases outward. Radial fractures develop from hoop stresses at the front of the divergent stress wave.[2] A second and equally important type of fracturing in the blast-fractured zone is spalling as discussed below.

b. Spalling.

(1) Natural joints and free faces promote spalling fragmentation. First there are air-rock interfaces, that is, the excavation surface or free face. Second there are a multitude of open fissures, bedding planes, etc., that constitute internal free faces.

(2) Spalling is caused by tensile stress resulting from interference between the tail portion of an incident compressional wave and the front of the same wave which has been transformed on reflection at the free surface into a tensional wave. Rocks being strong in compression but weak in tension[5] (Table 2-1) are particularly prone to spalling. They are able to transmit very high compressive stresses, but when these are transformed on reflection into tensile stresses, the rocks may fracture or spall.

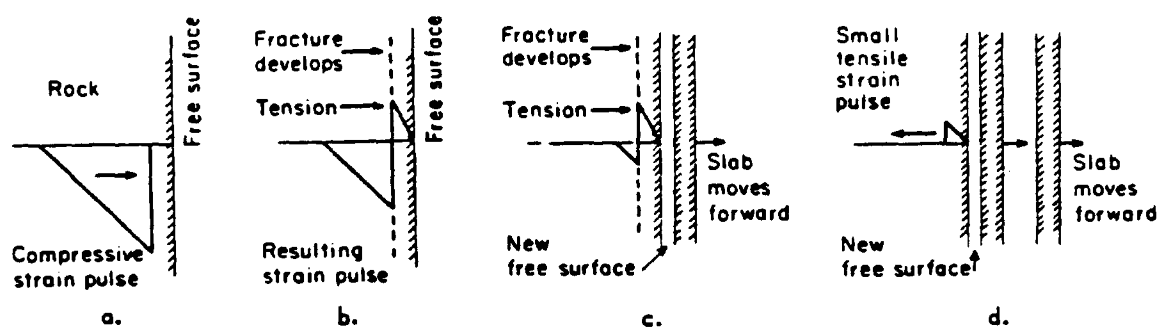
(3) The higher the ratio of compressive to tensile strengths, the more extensive the spalling becomes. The ratio is sometimes known as the blasting coefficient (para 6-2c). The harder and more competent rocks are more susceptible to spalling.

(4) As shown in Fig. 2-2, the spall fracture develops parallel to the reflecting surface. These new cracks, in turn, serve as reflecting surfaces converting following compressional waves to destructive tensional waves. Thus, other parallel spalls form until attenuation subdues the tensional waves to below the destructive level (tensile strength of rock), or until the spalling has migrated back to the explosion cavity.

Table 2-1. Unconfined Compressive and Tensile Strengths of Rocks and Blasting Coefficients[1]

Rock Type	Unconfined Compressive Strength psi	Unconfined Tensile Strength psi	Blasting Coefficient
Quartzite	31,650	2,510	13
Quartzite	22,250	2,550	9
Quartzite	43,700	2,950	15
Argillite	31,400	2,620	12
Diabase	53,300	3,550	15
Basalt	9,800	730	13
Basalt	26,500	1,990	13
Basalt	40,800	4,020	10
Gabbro	29,600	2,150	14
Gabbro	25,050	1,810	14
Granite	24,350	1,780	14
Granite	22,000	1,300	17
Granite	28,950	1,850	16
Marble	18,150	1,010	18
Limestone	14,200	820	17
Limestone	17,800	910	20
Dolomite	13,800	600	23
Hornblende schist	29,600	1,080	27

(1) The strengths and blasting coefficients are not necessarily representative in general of the particular rock type.



(Courtesy of The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.)

Fig. 2-2. Tensile fracture by reflection of a compressive strain pulse (after Atchison[1])

c. Combined Role of Expanding Gases. The combined effects of rock fracturing by compressional and tensional waves are greatly augmented by hot expanding gases that work their way along fractures, churning pieces together and moving large blocks en masse. Fragmentation results in part from collision of pieces. The shock wave is responsible for only a part of the breakage. The whole process is a complex interaction of several processes.